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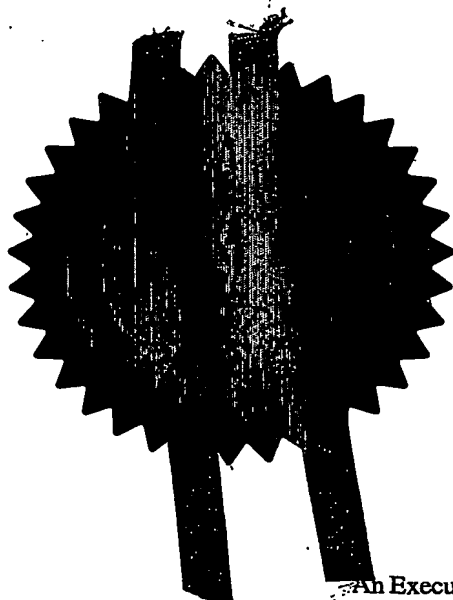
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DESCRIPTION

A CHARGE PUMP CIRCUIT

This invention relates to a charge pump circuit. In particular, it relates to
5 a charge pump circuit which is capable of providing voltage outputs which are
not integer multiples of the supply voltages. The invention also relates to
electronic devices including such a circuit, particularly but not exclusively,
large-area electronic (LAE) devices such as an active matrix liquid crystal
display (AMLCD) or another type of active matrix display. A semiconductor
10 device or semiconductor integrated circuit is another device form, in which the
charge pump circuit may, for example, be integrated.

Charge pump circuits are known for providing a boosted DC voltage
from a lower DC voltage supply. The boosted voltage may be more positive
15 than the high level of the input supply voltage or, alternatively, more negative
than the low level of the input supply voltage. Such circuits may comprise a
series of voltage boosting stages which each include a switch connected to a
capacitor, the switch controlling the flow of charge onto the capacitor. Such a
circuit is disclosed for example in WO 02/061930. The switch of each stage is
20 provided at the input of the stage, and the output of each stage is the junction
between the switch and capacitor. The input to the circuit is a DC current
supply at the lower voltage magnitude. The capacitors are connected
alternately to one of two complementary clocked control lines which control the
switching operation, which in turn controls the so-called pumping of charge
25 along the series of stages.

During operation of the circuit, one clock cycle causes a charge stored
on the capacitors connected to one of the control lines to be passed to the
capacitors of the respective next stage. The voltage across the capacitors
increases progressively along the series of voltage boosting stages. A larger
30 number of stages leads to a larger output voltage for the circuit.

For a given power supply with a low voltage level of $V_{SS} = 0V$ (for the
sake of explanation only) and a high voltage level of V_{DD} , charge pump circuits

of the type disclosed in WO 02/061930 are used to generate a voltage of $(n+1)V_{DD}$ in the case of a positive charge pump and $-nV_{DD}$ in the case of a negative charge pump, where n is an integer equal to the number of stages in the charge pump. However, it is often the case that the output voltage required is not equal to an integer multiple of the power supply voltage V_{DD} . In this case, it is known to use additional circuitry to regulate the output voltage to the required value, which provides a fundamental limit to the theoretical efficiency that can be achieved.

For example, a single stage positive charge pump with a 5V input voltage would normally generate an output voltage of 10V. If this is regulated down to a required output voltage of 7.5V, the maximum theoretical efficiency of the charge pump is reduced to 75%.

US 5 790 393 discloses a charge pump circuit for generating a fractional multiple of the supply voltage. The capacitor storing the pumped charge is connected in parallel with an additional capacitor at the output of the circuit in order to reduce the output voltage to a level which is the required fractional multiple. Although this circuit does not use a voltage regulator, it also has the disadvantage of a limited maximum theoretical efficiency.

In addition to providing fractional multiples of the voltage supply lines, there is often a need both for a voltage above that of the high voltage supply line and a voltage below that of the low voltage supply line.

One example of an application of charge pump circuits is in portable electronic devices having display screens. A relatively high voltage is needed for the display, for example 15V, whereas the device is to be powered by a relatively low voltage supply, for example 3V. The use of a voltage boosting device such as a charge pump circuit is clearly appropriate.

According to the invention, there is provided a charge pump circuit comprising:

- a voltage increasing stage;
- a voltage decreasing stage in parallel with the voltage increasing stage;
- and

a shared input to the voltage increasing and voltage decreasing stages.

The invention addresses the problem of generating two (or possibly more) boosted voltages, one of which is in the positive sense and one of which is in the negative sense relative to the power supply voltages. Furthermore, the circuit enables voltages to be generated which are not equal to an integer multiple of the power supply voltage. In particular, charge used in the pumping of one stage can be recycled to the other stage, as the voltage increasing stage and the voltage decreasing stage require charge pumping in opposite senses. Thus, an efficient means of generating the required voltages is provided.

The voltage increasing stage is preferably for increasing an input voltage by an integer multiple of the difference between a low supply line voltage and a high supply line voltage and the voltage decreasing stage is for decreasing an input voltage by an integer multiple of the difference between a low supply line voltage and a high supply line voltage. By selecting the input voltage at a value between the supply line voltages, the output voltages are non-integer multiples of the supply line voltages.

The voltage increasing stage may comprise one or more charge pump sections, each for increasing the input voltage by the difference between a low supply line voltage and a high supply line voltage. Similarly, the voltage decreasing stage may comprise one or more charge pump sections, each for decreasing the input voltage by the difference between a low supply line voltage and a high supply line voltage.

Each charge pump section preferably comprises an input switch and an output switch in series connected together at a junction node, and a charge pump capacitor connected between junction node and a control line.

Each charge pump section may comprise a first input switch and output switch in series connected together at a first junction node, a second input switch and output switch in series connected together at a second junction node, a first charge pump capacitor connected between the first junction node and a first control line and a second charge pump capacitor connected between the second junction node and a second control line. This provides

two pump circuits in parallel, so that charge pumping can be performed during all clock cycles.

In another arrangement each charge pump section of the voltage increasing stage and of the voltage decreasing stage may comprise a first input switch and output switch in series connected together at a first junction node, and a second input switch connected between the input and a second junction node, a first charge pump capacitor connected between the first junction node and a first control line and a second capacitor connected between the second junction node and a second control line, wherein the second junction node provides the control signals for the first input and output switches.

In this arrangement, only one charge pump capacitor is provided in each charge pump circuit, and the other capacitor is for generating appropriate switch control signals. Complementary signals are again applied to the first and second control lines.

The invention also provides an integrated circuit device or other electronic device which may be formed using, for example, low temperature poly-silicon processing and which includes a charge pump circuit of the invention. The device may comprise an active matrix liquid crystal display device, with the charge pump circuit and a TFT switching array for the display being provided on a common substrate.

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic circuit diagram of a charge pump circuit in accordance with the invention;

Figure 2 is a more detailed circuit diagram showing one implementation of the circuit of Figure 1; and

Figures 3A and 3B are used to explain in greater detail the operation of the circuit of Figure 2; and

Figure 4 is a more detailed circuit diagram showing another implementation of the circuit of Figure 1; and

Figure 5 is a schematic plan view of a LAE device incorporating a display and a charge pump circuit.

The invention provides a circuit capable of generating two (or possibly
5 more) boosted voltages, one of which is in the positive sense and one of which
is in the negative sense relative to the power supply voltages. Furthermore,
the circuit enables these voltages to be equal to non-integer multiples of the
power supply voltage. This provides an efficient way of generating voltages for
example for an analogue switch, where it may be necessary to generate
10 voltages above and below the power rails in order to ensure the switch can be
properly turned on and off. This capability is required in a large number of
analogue circuit applications.

Figure 1 shows in schematic form a charge pump circuit 1 in
accordance with the invention, for illustrating the basic idea behind the
15 invention.

The circuit includes a voltage boosting stage 1 and a voltage
decreasing stage 2. Each stage has an input switching device S_{1A} , S_{2A}
(referred to generally as S_{nA} in the following) and a charge pump capacitor
 C_{P1} , C_{P2} (referred to generally as C_{Pn} in the following) connected in series
20 between the input to the stage and a respective voltage control terminal 4, 6.
The output from each stage 1, 2 comprises the node between the switching
device S_{nA} and the capacitor C_{Pn} . This node is connected to the output of the
stage through an output switch S_{1B} , S_{2B} (referred to generally as S_{nB} in the
following).

25 The input and output switches S_{nA} , S_{nB} are switched with
complementary signals (Φ' and $/\Phi'$) so that the charge pump capacitor is
alternately connected to the input 8 and to the output of the stage.

The voltages on the voltage control terminals 4, 6 are switchable
between two levels. This is achieved by providing a square tooth waveform to
30 the terminals 4, 6. The voltages supplied to the control voltage terminals 4 and
6 alternate voltage levels corresponding to the voltages of a high voltage

supply rail and a low voltage supply rail. For example, the low voltage supply rail may be a ground connection.

The voltage on one terminal 4 (Φ) is the complement of the voltage on the other 6 (Φ), so that one signal has opposite polarity to the other, but is
5 clocked at the same time.

The same control signal waveform timing may be used for the control of the input and output switches as for the control lines 4,6. In other words Φ can have the same transitions as Φ' . Thus, when CP1 is connected to the low voltage and CP2 is connected to the high voltage, switches S1A and S2A are
10 closed (low impedance) and S1B and S2B are open (i.e. high impedance). Similarly when CP1 is connected to the high voltage and CP2 is connected to the low voltage, switches S1A and S2A are open (high impedance) and S1B and S2B are closed (low impedance). The actual nature of the control signals Φ' and Φ depends upon the nature of the switches.

15 In operation of each stage, a DC input voltage V_{in} is applied to the input 8 of the charge pump circuit. This voltage source supplies a mean current that is approximately equal to the difference in the mean load currents drawn at the outputs, so $I(V_{in}) = I_{L1} - I_{L2}$. If I_{L2} is greater than I_{L1} , the V_{in} will sink current, whereas if I_{L1} is greater than I_{L2} it will supply current.

20 Taking the voltage boosting stage 1 by way of example, when the input switch S_{1A} is closed, charge flows to the capacitor C_{P1} , to charge it to the input voltage (less any voltage drop across the switch). This charge is provided to the capacitor when the control terminal 4 is connected to the low control voltage (e.g. 0V) and the input switch is closed. At the next clock cycle, and
25 after the capacitor has charged, the switch S_{1A} is opened, and the voltages on the control terminals are reversed. The voltage across the capacitor C_{P1} will then add to the new higher voltage (e.g. 5V) on the control terminal 4, so that an increased voltage appears at the output of the stage.

This increased output voltage is provided to the output through the
30 closed output switch S_{1B} .

The voltage decreasing stage 2 in Figure 1 operates in similar manner, but provides a step decrease in the voltage corresponding to the magnitude of

the voltage difference between the high and low power rails (shown as 0V and V_{DD} in Figure 1).

The operation of the circuit is achieved after an initial settling period which is required for the output voltages to reach their steady state levels. The output voltages rise and fall around this steady state level as charge is pumped along the circuit and current is supplied to the load. The magnitude of this ripple is reduced by increasing the size of the capacitors connected at the output of the charge pumps. The charge pumping operation is well known and will not be described in further detail.

In accordance with the invention, the voltage boosting and voltage decreasing stages 1, 2 share a common input V_{in} . The input voltage V_{in} lies between the power supply rail voltages. In conventional circuits, a negative charge pump would have its input connected to the low voltage supply rail and the positive charge pump would have its input connected to the high voltage supply rail V_{DD} . By connecting together the two inputs, the efficient generation of non-integer multiples of the power supply voltage is provided, because charge injected by the voltage decreasing charge pump can be recycled back into the voltage increasing charge pump. This minimises the current that must be supplied by the voltage source V_{in} .

Decoupling capacitors C_{L1} and C_{L2} are provided at the outputs, and connected to ground. These capacitors could in fact be connected to any low impedance constant voltage source. The decoupling capacitors are charged (i.e. pumped) to the output voltage during the start-up phase. They serve to minimise the ripple in output voltage during operation (the larger they are the lower the ripple). This is required because the charge on C_{L1} and C_{L2} is topped up once per clock cycle, but the load is likely to draw current continuously. The decoupling capacitors are likely to be off-chip external components.

The operation of the circuit will now be described in further detail assuming the low power line voltage V_{SS} to be 0V and the high power line voltage to be V_{DD} . The circuit in Figure 1 generates a positive output voltage $V_{out1} = V_{in} +$

V_{DD} and a negative output voltage $V_{out2} = V_{in} - V_{DD}$, where V_{in} is a voltage between 0 and V_{DD} .

Although the difference between V_{out1} and V_{out2} is always equal to $2V_{DD}$, the absolute levels of V_{out1} and V_{out2} can be adjusted from between $2V_{DD}$ and 0V respectively at the upper end down to V_{DD} and $-V_{DD}$ respectively at the lower end, depending on the value of V_{in} . This circuit offers advantages over conventional approaches when the required output voltages lie between these two limits. This is because the negative charge pump that generates V_{out2} injects charge back towards the input voltage source V_{in} . However, at the same time the positive charge pump that generates V_{out1} draws charge from the voltage source V_{in} . Consequently, the net effect is that charge from the negative charge pump can be recycled back into positive charge pump.

Figure 1 also represents the load driven by the two generated voltages as a first current source I_{L1} connected between the boosted voltage and the low power supply line voltage (ground in this example), and a second current source I_{L2} connected between the reduced voltage and the low power supply line voltage. These load currents depend upon the load driven by the circuit.

If the load currents I_{L1} and I_{L2} are equal, there is no net current flow into or from the voltage source V_{in} , which means that the voltage source can be designed with a high resistance. In the case where V_{in} is a voltage source with 100% efficiency, the charge pump switches are ideal and the pump capacitors are infinite, the theoretical efficiency is equal to 100% provided that I_{L1} is greater than or equal to I_{L2} . If I_{L1} is less than I_{L2} and charge injected into the voltage source V_{in} cannot be recycled, then the efficiency decreases accordingly.

The circuit in Figure 1 shows charge pumps formed using switches, but diodes could instead be used. Also, the positive and negative charge pumps illustrated in Figure 1 have only a single stage.

The principle can be easily extended to charge pumps with multiple stages, in which case the positive output voltage becomes $V_{outp} = V_{in} + nV_{DD}$ (where n is the number of stages in the positive charge pump) and the

negative output voltage becomes $V_{outn} = V_{in} - mV_{DD}$ (where m is the number of stages in the negative charge pump).

5 In a multiple stage arrangement, charge flows (or is pumped) from the capacitor in one stage to the capacitor in the next. The capacitor in next stage has the opposite control voltage applied to it at this time, so that the capacitor of this next stage has a higher voltage across it than the voltage across the capacitor in the previous stage. The capacitor voltage thus increases along the series of stages.

10 The voltage across one capacitor will be greater than the voltage across the previous capacitor by the difference between the control voltages (ignoring the voltage drop across the switches). This is the so-called boost voltage.

In a chain of charge pumps, adjacent pumps are controlled by complementary control signals, so that there are two voltage control terminals each associated with a different set of voltage boosting stages.

15 There can also be a number of positive charge pumps (each with a number of stages) and a number of negative charge pumps (each with a number of stages) connected to the same input voltage source V_{in} . Again, the criteria for obtaining the optimum efficiency due to charge recycling is that the current injected by negative charge pumps back towards the input voltage source V_{in} should be less than or equal to the current drawn by the positive charge pumps from the source V_{in} .

20 In order to ensure that the current is properly recycled from the negative to the positive arms of the charge pumps, some care may be required in the design of the voltage source V_{in} . Specifically, it may be necessary to design it with a particular resistance and to use a decoupling capacitor on the output: 25 This is a known technique. Also if the load current in the positive arms is less in magnitude than the load current in the negative arms so that current is drawn from the voltage source V_{in} , it is desirable that V_{in} should be made as efficient as possible. Circuits for efficiently generating a voltage between the power supply voltages are also well known. For example a capacitive divider 30 circuit can generate $V_{DD}/2$ with an ideal efficiency (assuming ideal switches and infinite capacitors) of 100%.

A more detailed example of a circuit implementation is shown in Figure 2, again each of the charge pumps consists of a single boosting stage, for simplicity. The output loads are represented as resistors R_{L1} and R_{L2} in Figure 2. In Figure 2, NMOS transistors are designated as "N" and PMOS transistors are designated as "P".

The voltage increasing stage 1 and the voltage decreasing stage 2 are implemented using poly-silicon TFTs (thin film transistors) and suitable for integration into an active matrix LCD display with input supply voltages of 5V and 0V. From these input voltages, the circuit is used to generate +7.5V and -2.5V, which are required for CMOS switches to ensure they can be properly turned on and off.

Each stage 1, 2 is associated with two charge pump capacitors C_{p1a} , C_{p1b} and C_{p2a} , C_{p2b} . Each capacitor connects to the junction between an input transistor switch N_{1a} , N_{1b} , P_{2a} , P_{2b} and an output transistor switch P_{1b} , P_{1a} , N_{2a} , N_{2b} . Thus, each stage effectively comprises two of the charge pump arrangements shown in Figure 1, arranged in parallel with each other. This arrangement enables charge pumping to be performed during all cycles.

In Figure 2, the two charge pumps in parallel enable appropriate gate voltages to be generated simply for the input and output switches, which are implemented as transistors. These gate voltages have a transition of equal magnitude to the clock transition, but both levels are shifted up (or down) by an amount equal to V_{in} .

The switches may instead be implemented as diodes, and no control signal are then required, as the diodes turn on and off as a natural consequence of the way the charge pump circuit functions.

The operation of each stage will be described in detail with reference to Figures 3A and 3B.

Figure 3A shows the components of the voltage boosting stage 1. Voltages are indicated in the Figure assuming the low power rail to be 0V and the high power rail to be 5V. Figure 3A shows the cycle in which the upper control terminal is at the low voltage and the lower control terminal is at the high voltage. The transistors and capacitors have not been given references

in Figure 3A and 3B, as they correspond to those of Figure 2. The references of Figure 2 are thus used to identify the corresponding components in Figure 3. The arrows in Figures 3A and 3B represent the flow of charge.

5 The input voltage of 2.5V charges the upper capacitor C_{p1b} to 2.5V through transistor N_{1b} which is turned on. The equilibrium at the output is 7.5V, and as shown the lower capacitor C_{p1a} is charged with 2.5V across it and thereby presents 7.5V to the output. Charge is pumped to the output through transistor P_{1a} to maintain the output at this voltage.

10 Figure 3B shows the cycle in which the upper control terminal is at the high voltage and the lower control terminal is at the low voltage.

The input voltage of 2.5V charges the lower capacitor C_{p1a} to 2.5V through transistor P_{1a} which is turned on. The upper capacitor C_{p1b} is charged with 2.5V across it and presents 7.5V to the output. Charge is pumped to the output through transistor P_{1b} to maintain the output at this voltage.

15 This arrangement thus provides charge pumping during all clock cycles.

The voltage decreasing stage 2 operates in the same way, although with charge flowing in the opposite direction.

20 As shown in Figure 2, the charge pump section of the voltage increasing stage 1 the charge pump section of the voltage decreasing stage 2 are connected together by the charge pump capacitors C_{p1a} and C_{p2a} which are connected together in series, with one of the control lines at the junction.

The circuit of Figure 2 has two charge pump capacitors for each charge pump stage. These capacitors need to be of a certain size to perform the charge pump operation, and this increases the area needed by the circuit.

25 Figure 4 shows an alternative implementation with just one pump capacitor per charge pump stage, C_{p1} and C_{p2} . Each charge pump stage also has only one output switch $P1$ and $N2$. Accordingly, charge pumping is performed by each stage during only one of the two cycles.

30 In the voltage increasing stage, one input switch $N1b$ and capacitor C_{bs1} are only used to generate a level shifted clock to drive the gate signals for the other input switch $N1a$ and the output switch $P1$. Similarly, in the voltage decreasing stage, the input switch $P2b$ and the capacitor C_{bs2} are

only used to generate a level shifted clock for the gates of the input switch P2a and the output switch N2.

As capacitors Cbs1 and Cbs2 are not used to pump charge into the circuit, their value can be much smaller than Cp1 and Cp2. This circuit is preferred, particularly if the values of Cp1 and Cp2 are too big to enable them to be integrated onto the glass.

Figure 5 shows an integrated circuit device 30 including an active matrix liquid crystal display device which uses a TFT switching array 32. The switching array and a charge pump circuit 34 are provided on a common substrate 36, and a low voltage power supply 38 (for example a 3V battery) provides power to the integrated circuit 36.

However, the present invention may be used with other types of device. Indeed, charge pumps are a very widely used circuit element found in many other applications. Examples include the generation of the programming and erase voltages for flash memories and in low voltage ICs where boosted voltages may be required by the analogue switches. Charge pumps may also be used in integrated control circuitry of a semiconductor power switch. The power switch may be, for example, a MOSFET. There are of course many more applications and various other modifications will be apparent to those skilled in the art.

CLAIMS

1. A charge pump circuit comprising:
a voltage increasing stage;
5 a voltage decreasing stage in parallel with the voltage increasing stage;
and
a shared input to the voltage increasing and voltage decreasing stages.
2. A circuit as claimed in claim 1, wherein the voltage increasing
10 stage is for increasing an input voltage by an integer multiple of the difference
between a low supply line voltage and a high supply line voltage and the
voltage decreasing stage is for decreasing an input voltage by an integer
multiple of the difference between a low supply line voltage and a high supply
line voltage.
- 15 3. A circuit as claimed in claim 1 or 2, wherein the voltage
increasing stage comprises at least one charge pump section.
4. A circuit as claimed in claim 3, wherein the voltage increasing
20 stage comprises a plurality of charge pump sections, each for increasing the
input voltage by the difference between a low supply line voltage and a high
supply line voltage.
5. A circuit as claimed in any one of claims 1 to 3, wherein the
25 voltage decreasing stage comprises at least one charge pump section.
6. A circuit as claimed in claim 5, wherein the voltage decreasing
stage comprises a plurality of charge pump sections, each for decreasing the
input voltage by the difference between a low supply line voltage and a high
30 supply line voltage.

7. A circuit as claimed in any one of claims 3 to 6, wherein the or each charge pump section of the voltage increasing stage and of the voltage decreasing stage comprises an input switch and an output switch in series connected together at a junction node, and a charge pump capacitor
5 connected between junction node and a control line.

8. A circuit as claimed in claim 7, wherein the or each charge pump section of the voltage increasing stage and of the voltage decreasing stage comprises a first input switch and output switch in series connected together at
10 a first junction node, a second input switch and output switch in series connected together at a second junction node, a first charge pump capacitor connected between the first junction node and a first control line and a second charge pump capacitor connected between the second junction node and a second control line.

15

9. A circuit as claimed in claim 8, wherein complementary signals are applied to the first and second control lines.

10. A circuit as claimed in claim 7, wherein the or each charge pump section of the voltage increasing stage and of the voltage decreasing stage
20 comprises a first input switch and output switch in series connected together at a first junction node, and a second input switch connected between the input and a second junction node, a first charge pump capacitor connected between the first junction node and a first control line and a second capacitor connected
25 between the second junction node and a second control line, wherein the second junction node provides the control signals for the first input and output switches.

11. A circuit as claimed in claim 10, wherein complementary signals
30 are applied to the first and second control lines.

12. A circuit as claimed in any one of claims 8 to 11, wherein the first input switch and output switch are operated in complementary manner.

13. A circuit as claimed in any one of claims 8 to 12, wherein the charge pump capacitor of at least one charge pump section of the voltage increasing stage and the capacitor of at least one charge pump section of the voltage decreasing stage are connected together.

14. A circuit as claimed in any preceding claim, wherein the voltage increasing stage is for increasing an input voltage by an integer multiple of the difference between a low supply line voltage and a high supply line voltage, the voltage decreasing stage is for decreasing an input voltage by an integer multiple of the difference between a low supply line voltage and a high supply line voltage and wherein a voltage is applied to the shared input between the low supply line voltage and the high supply line voltage.

15. An electronic device including a circuit as claimed in any one of the preceding claims.

16. A device as claimed in claim 15, wherein the device comprises a liquid crystal display.

17. A device as claimed in claim 16, wherein the circuit and a TFT switching array for the display are provided on a common substrate.

ABSTRACT

A CHARGE PUMP CIRCUIT

5 A charge pump circuit has a voltage increasing stage and a voltage decreasing stage in parallel, and sharing a common input. This allows charge to flow between the stages, so that charge used in the pumping of one stage is recycled to the other stage.

[Fig. 1]

10

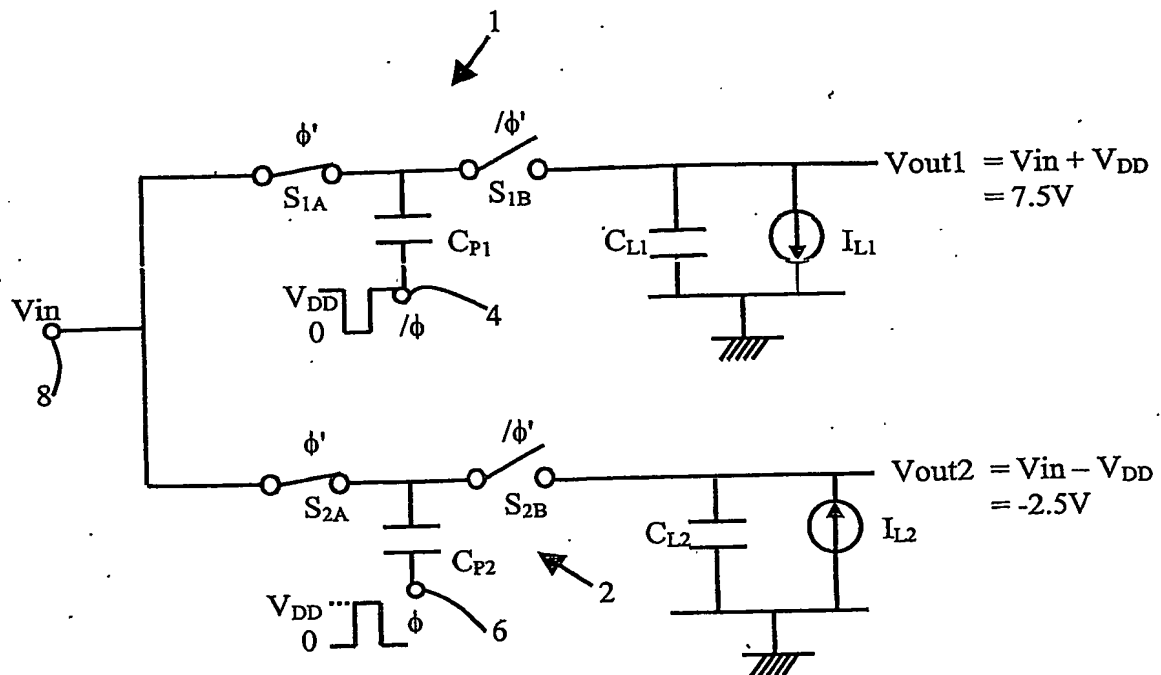


FIG. 1

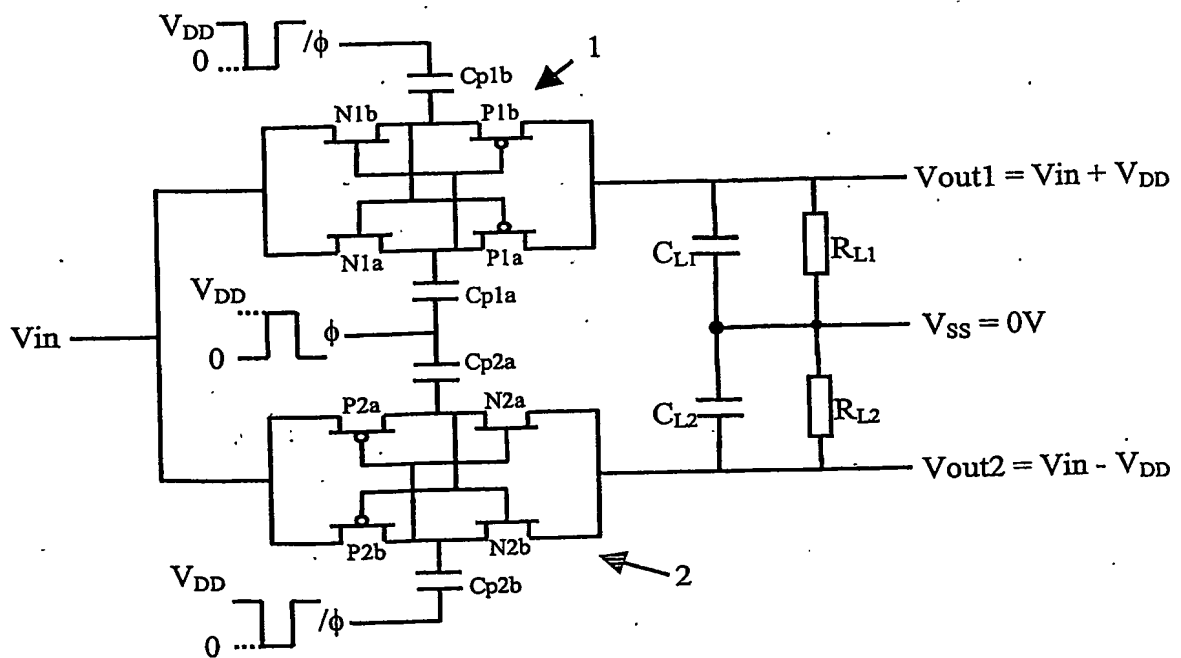


FIG. 2

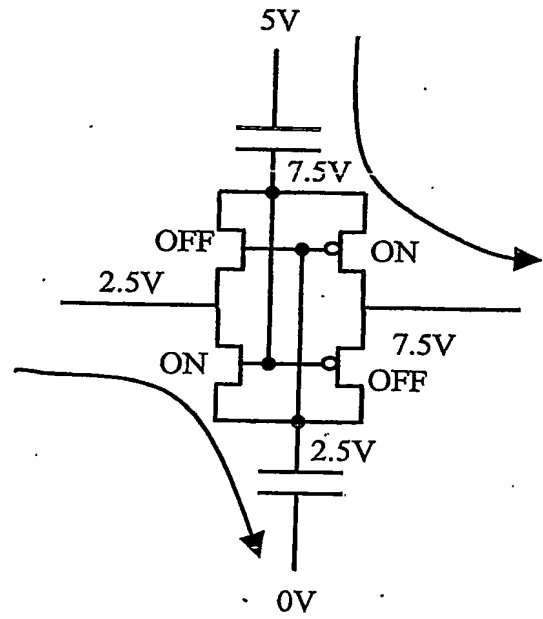
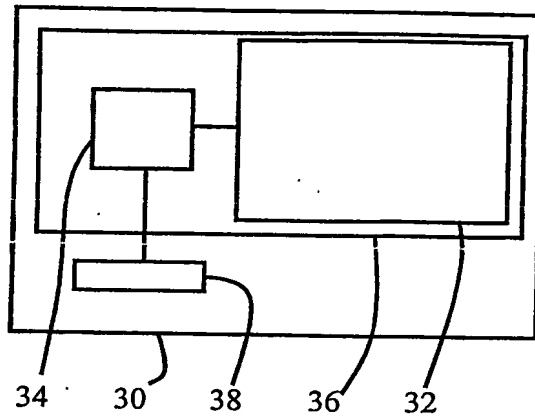


FIG. 3B



*FIG. 5*